

## **Shallow Water Mid-Frequency Research and SW06**

Dajun (DJ) Tang

Applied Physics Laboratory, University of Washington

1013 NE 40<sup>th</sup> Street, Seattle, WA 98105

phone: (206) 543-1290 fax: (206) 543-6785 email: [djtang@apl.washington.edu](mailto:djtang@apl.washington.edu)

Award Number: N00014-08-1-0077

<http://www.apl.washington.edu/projects/SW06/>

### **LONG-TERM GOALS**

To understand mid-frequency (1-10 kHz) acoustics in shallow waters through measurements and modeling, including propagation, reflection, and forward- and backscatter, as well as reverberation. The top-level goals of this effort are to understand the important environmental processes that impact mid-frequency sonar performances in shallow water environments, and to develop means to efficiently collect those environmental data.

### **OBJECTIVES**

The Shallow Water 2006 (SW06) project yielded abundant data sets carefully collected for the purpose of investigating mid-frequency (1-10 kHz) acoustics interacting with environments. Both acoustic data and relevant environmental data were measured contemporaneously to facilitate close model/data comparison. During FY10, continuing FY09 effort, research has been concentrated in the areas of data analysis and documentation of results, as well as planning of a shallow water reverberation experiment. An important underlining emphasis going forward is to define what is needed to conduct a 6.1 reverberation experiment at the mid-frequency where environmental processes relevant to the reverberation modeling are also measured. The objectives are:

1. Analyze mid-frequency propagation data in shallow water in the presence of small ambient internal waves. Specifically, documentation of intensity field and its fluctuations (scintillation index). The significance of the work is that little has been done on this topic in shallow water environments. The effort is to support application of mid-frequency sonar in shallow water environments.
2. Comparison geoacoustic inversion results based SW06 propagation data to sediment sound speed data from in situ measurements using the SAMS (Sediment Acoustics Measurement Systems).
3. With a new DURIP fund, improving the SAMS to extend its capability to lower frequencies (700 Hz) in order to better understand sediment dispersion.
4. Modeling bottom ripple fields as a non-Gaussian process and studying its role in "clutter."
5. Development of an efficient modeling capability based on PE (Parabolic Equation) to model mid-frequency reverberation.

Report Documentation Page				Form Approved OMB No. 0704-0188	
Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.					
1. REPORT DATE <b>2010</b>		2. REPORT TYPE		3. DATES COVERED <b>00-00-2010 to 00-00-2010</b>	
4. TITLE AND SUBTITLE <b>Shallow Water Mid-Frequency Research and SW06</b>				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S)				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) <b>University of Washington, Applied Physics Laboratory, 1013 NE 40th St, Seattle, WA, 98105</b>				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>4</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

## APPROACH

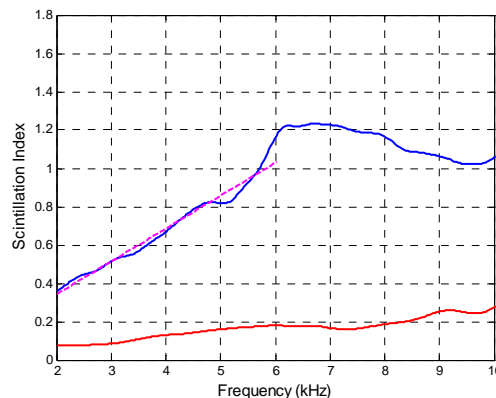
Because mid-frequency data in shallow water are limited, we continue to base our analysis and development of models on data sets collected in SW06 off the New Jersey coast, where both acoustics and environmental data are available. This is crucial for achieving the goal of quantitative model/data comparisons of sound fields interacting with bottom, surface, and the water column. Based on work from the previous two years, we made oceanographic models to predict sound propagation under the influence of internal tides. Another important area is the study of sound intensity fluctuation, where we identified a single arrival from other arrivals to quantitatively analyze the scintillation index. We also approached the mid-frequency problems theoretically in two topics: one is the modeling sediment ripple fields as a non-Gaussian process that can be a "clutter" mechanism; the other is formulating reverberation in a range-dependent environment by the combination of using the PE as the two-way propagator and perturbation theory for backscatter.

## WORK COMPLETED

1. Geoacoustic inversion (collaboration with Yang and Jackson).
2. Mid-frequency intensity scintillation index analysis (collaboration with Rouseff, Henyey, and Yang).
3. Formulation and initial numerical implementation of Monte Carlo reverberation model based on PE and perturbation theory (with Jackson).

## RESULTS

1. Scintillation Index. The figure below shows the measured scintillation index of a single arrival at 1 km range going through two upper-turning points as a function of frequency (blue). The red curve is scintillation of a bottom bounce arrival as a reference. The pink line is an estimate of the slope of the scintillation index as a function of frequency. The trend demonstrates that the scintillation index goes from under saturation, to over saturation (around 6 kHz) and saturation (9-10 kHz). It was previously anticipated that saturation would not happen at such short range. This result provides quantitative explanation to why match-field processing works better at low-frequency, where scintillation is low, but is problematic with increasing frequency. This result also provides an explanation for why low-frequency geoacoustic inversion techniques work better, because at low-frequency suffers litter intensity fluctuations, as can be projected from the figure. A paper on this topic is written.



2. A new model of reverberation capable of dealing with range-dependent environment is developed. The parabolic equation method is used to handle the two-way propagation, and first order perturbation theory is used to handle the backscatter. Because the calculation time is independent of the number of realizations, this method is much faster numerically than any models available. Another advantage of this method is that it can easily handle complications such as internal waves and swells. Using this new model, we have investigated the effect of sediment ripples and internal waves as clutter mechanisms. Also investigated is how to compare this model to some Navy standard models to understand the compromise between fidelity and speed.

## **IMPACT/APPLICATIONS**

We anticipate impacts in the following areas: first, the work on scintillation index will help open further research of sound wave propagation in shallow water as a problem of wave propagation in random media, linking shallow water research to that in the deep ocean, both managed by ONR's acoustics program. Second, the new reverberation model makes it possible to simulate a large number of shallow water reverberation problems. On the very top of our agenda, we would use the model to investigate the following hypothesis: shallow water clutter is due to the combination of forward scatter that diverts sound to higher grazing angles, and backscatter from these high angle incident energy.

## **RELATED PROJECTS**

ONR reverberation workshop series (Thorsos and Perkins)

## **PUBLICATIONS**

1. Tang, D., and D. R. Jackson, "Scattering from an arbitrarily shaped rough interface embedded in heterogeneous fluids," J. Acoust. Soc. Am., (In preparation).
2. Henyey F., K Williams, J. Yang, and D. Tang, "Simultaneous nearby measurements of acoustic propagation and high-resolution sound speed structure containing internal waves," *IEEE J. Oceanic Engineering* (in press).
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5. Tang, D. Kevin L. Williams, and Eric I. Thorsos "Utilizing high frequency acoustic backscatter to estimate bottom sand ripple parameters," *IEEE J. Oceanic Engineering*, Vol. 34, 431-443 (2009).
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12. Rouseff, D. D. Tang, K. L. Williams and Z. Wang, "Mid-frequency sound propagation through internal waves at short range with synoptic oceanographic observations," *J. Acoust. Soc. Am.* **124** EL73 (2008).
13. Yang, J., D. Tang, and K. L. Williams, "Direct measurement of sediment sound speed using SAMS in SW06," *J. Acoust. Soc. Am.* **124**, EL116 (2008).
14. Lynch, J. and D. Tang, "Overview of Shallow Water 2006 *JASA EL* Special Issue Papers," *J. Acoust. Soc. Am.* **124**, EL63 (2008).
15. Tang, D. J. N. Moum, J. F. Lynch, P. Abbot, R. Chapman, P. H. Dahl, T. F. Duda, G. Gawarkiewicz, S. Glenn, J. A. Goff, H. Graber, J. Kemp, A. Maffei, J. D. Nash, and A. Newhall, "Shallow Water '06: A Joint Acoustic Propagation/Nonlinear Internal Wave Physics Experiment," *Oceanography* Vol. 20, No. 4 pp156-167 (2007).